ACC932 Materials and Processes Technology Development

Carbon Fiber SMC

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5-20-09

Project ID: lm_07_kia

AUTOMOTIVE COMPOSITES CONSORTIUM

Overview

Timeline • Start – May, 2007 • Finish – Dec, 2010 • 25 % Complete	**Barriers** • Poor carbon fiber interface with automotive grade resin systems • Poor mold flow • Inconsistent material properties • High costs

Budget
• Total –
  • DOE: $310,000 (including capital)
  • Contractors: $60,000
• $75,000 (plus $110,000 ACC capital) in 2008
• $54,000 for 2009
	Partners
	• Continental Structural Plastic (CSP), a Tier One supplier
	  • Discounted compounding and molding
	• Zoltek, a carbon fiber manufacturer
	  • Discounted fibers

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Objectives

- To develop a carbon fiber reinforced SMC with physical properties and processing significantly superior to current carbon fiber SMC materials, in order to expand its application for automotive light-weighting.
  - > 200 MPa Tensile Stress
  - > 40 GPa Tensile Modulus
  - > 0.5% Tensile Strain to failure
  - < 10% COV
- To focus on lower cost carbon fibers and commercial viability.

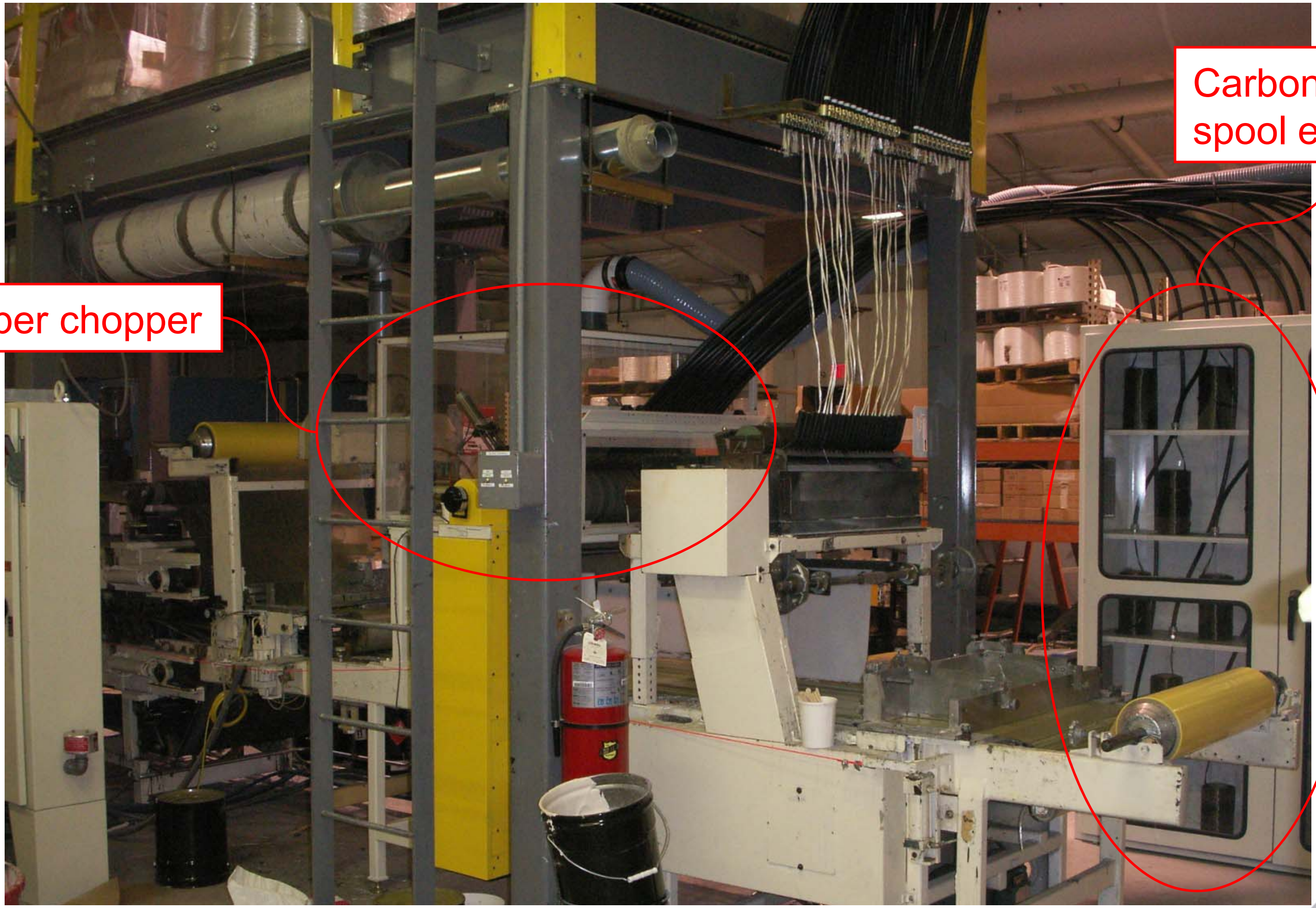
Approach

- Work directly with a Tier One automotive SMC compounder/molder to develop an improved low cost carbon fiber SMC. Utilize the supplier's familiarity with existing material systems to rapidly implement the new technology.
- Investigate methods to improve carbon fiber distribution and fiber to resin matrix adhesion.
  - Fiber resin wet-out and adhesion
  - Molding consistency
- Develop structural SMC first, follow by Class-A material.

Milestones

- Secure Tier One supplier
- Modify SMC compounder
  - Funding
  - Modification
- Determine material goals
- Compound baseline material
- Develop improved material
- Mold demonstration automotive part

SMC Compounder at CSP



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Carbon Fiber Chopper

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Technical Accomplishments – FY2008

- Existing glass fiber SMC compounder was successfully modified to chop carbon fibers. This includes safety features for dealing with air born carbon fibers.
- Completed testing of currently available carbon fiber SMC materials, used to set project targets for an improved material.
- Conducted fiber “sizing” study of Panex 35 carbon fibers, determined best initial sizing and amount of sizing to use with automotive vinyl ester resin systems.

Future Work

- Compound and test baseline SMC material.
- Compound and test smaller tow carbon fibers to evaluate fiber distribution and wet out.
- Investigate methods to improve distribution and wet-out of low cost/large tow carbon fibers.
- Evaluate flow-ability of materials.
- Modify successful structural materials for improved surface appearance.
- Investigate/compound current “fast” epoxy SMC resin systems for comparison.

Summary

- Program targets were set to provide a commercially viable carbon fiber SMC material.
- CSP was selected as the Tier One supplier and their existing SMC compounder was upgraded to handle chopping of carbon fibers.
- An initial fiber sizing study was completed at Zoltek (the low cost carbon fiber supplier).

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Bond-Line Read-Through

Kedzie Fernholz

Ford

5-20-09

LM07

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ACC Bond-Line Read-Through Project

Overview

- Timeline
  - Project Start: 3Q05
  - Project End: 3Q10
  - Percent Complete: 60%
- Budget
  - Total project funding
    - DOE $600k
    - Contractor $45k
  - FY08 Funding: $110K
  - FY09 Funding: $110K
- Barriers Addressed
  - Robust Joining Technologies for Composites
  - Barriers to Implementation of Class “A” Carbon Composites
  - Affordable Carbon Composites
- Partners
  - Visuol Technologies
  - Meridian Automotive Systems (Experimental)
  - Multimatic Engineering Services (Analytical)

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ACC Bond-Line Read-Through Project

Objectives

Project Objective

Develop the ability to predict bond-line read-through in the design phase to enable use of minimum thickness closure panels

FY08 Project Objectives

- Phase 1 – Measurement Development
  - Evaluate and Refine Algorithm Converting Raw Data to Meaningful Quantitative Value
- Phase 2 – Determine BLRT Root Cause
  - FY08 Experiments
    - Initial Factor Screening Experiments
    - Effect of Cure Temperature Experiment
    - Effect of Adhesive Volume Experiments
    - Flange Coverage Experiment

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ACC Bond-Line Read-Through Project
FY08 Milestones

- Phase 1 – Measurement Development
  - Demonstrate the developed measurement algorithm is applicable to experimental panels
  - Determine repeatability and reproducibility of the measurements.
- Phase 2 – Determine BLRT Root Cause
  - Identify factors with a high impact on BLRT severity
  - Identify at least two factors with a minimal impact on BLRT severity

Approach

- Phase 1 – Measurement Development
  - Develop a measurement technique that quantifies the visual severity of surface distortions caused by bond-line read-through in a way that correlates with visual assessments
- Phase 2 – Determine BLRT Root Cause
  - Experimentally determine which material and process factors are the primary contributors to BLRT-induced distortions
  - Create experimental data to validate analytical models
- Phase 3 – Develop an Analytical Model for Predicting BLRT
  - Determine the material properties and analytical modeling techniques necessary to predict BLRT-induced distortions
  - Identify design principles to minimize the occurrence of BLRT and allow OEMs to use minimum thickness outer panels in closures

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FY08 Technical Accomplishments

- **Phase 1**
  - Algorithm demonstrated to successfully quantify BLRT distortions on experimental assemblies
  - Repeatability & reproducibility of overall system found to be inadequate
    - Assemblies are measured three times to improve data
    - Evaluation of a more "production representative" system to occur in FY09
- **Phase 2**
  - Completed initial screening experiment, including analysis
  - Completed initial follow-up experiments, including analysis
    - Effect of Cure Temperature Experiment
    - Effect of Adhesive Volume Experiments
    - Flange Coverage Experiment

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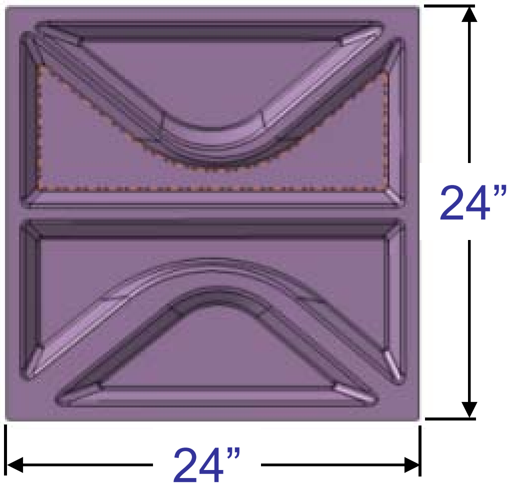
Phase 2: Experimental Analysis Bond-line Read-through Samples

- Sample Geometry
  - 24”x24” flat panel “outer panel”
  - “Inner panel” tool with 4 flange widths
- Manufacturing Process
  - Electrically heated bond nest
  - Bond thickness controlled by bonding press
  - Robotic application of adhesive



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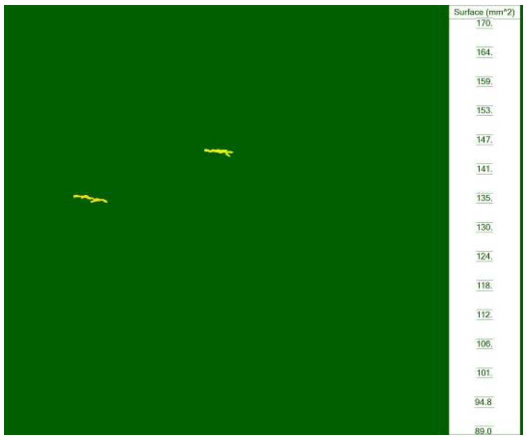
All experiments are being conducted at Meridian Automotive’s Shelbyville & Rushville, IN Plants

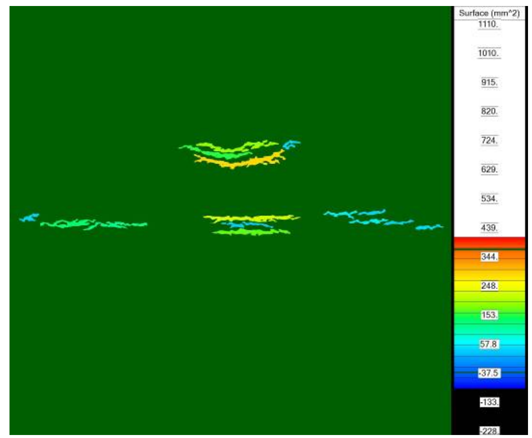
Phase 2: Experimental Analysis

Screening Experiment Results

- Stiffness (Modulus) of Outer Panel



2.5mm SMC



0.7mm Steel

Bending (structural) stiffness is more important than Young's modulus!

The deflection of a plate is a function of the thickness cubed!

$$U_{plate} = \frac{E\,t^3}{24\,(1 - \nu^2)} \int \left\{ \frac{\delta^2 u_y}{\delta u_x^2} + \frac{\delta^2 u_y}{\delta u_z^2} \right\} dx\,dz$$

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Phase 2: Experimental Analysis

Screening Experiment Results

- Type of bond nest had no effect
  - This may be due simply to the large percentage of the panel that is heated

“Full” Nest

“Skeletal” Nest

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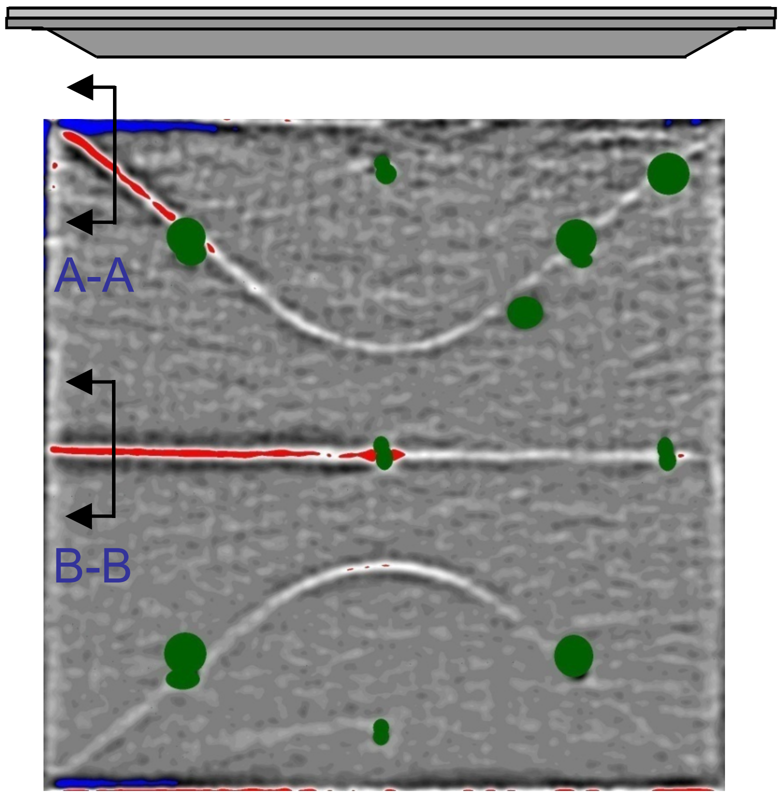
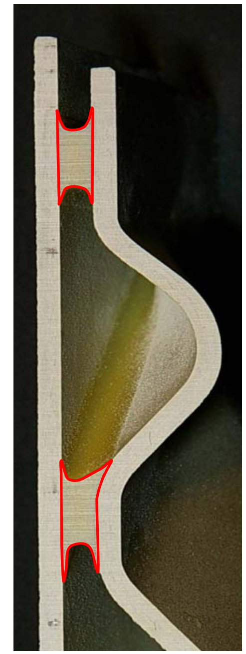
Phase 2: Experimental Analysis

Screening Experiment Results





Section A-A

Section B-B

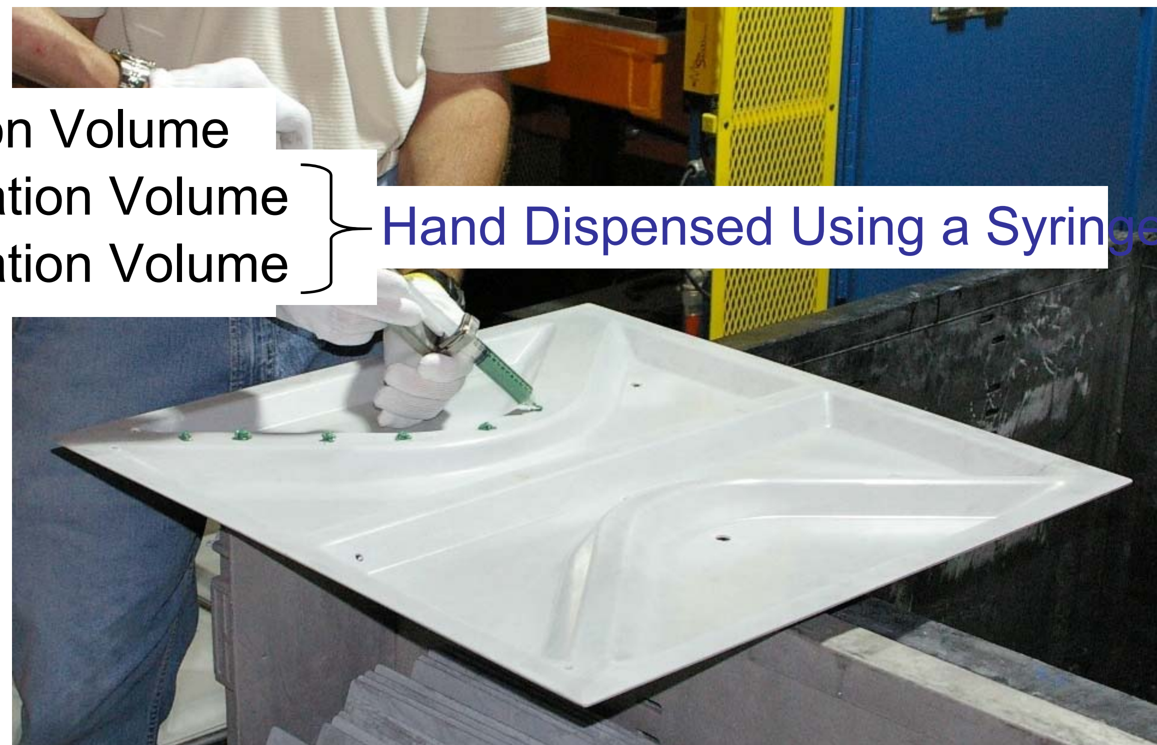
Note: Section lines on curvature map are approximate locations

Phase 2: Experimental Analysis

Drop Size Evaluation

- Adhesives
  - Epoxy
  - Urethane
- Drop Sizes
  - Robotic Application Volume
  - ½ Robotic Application Volume
  - ¼ Robotic Application Volume

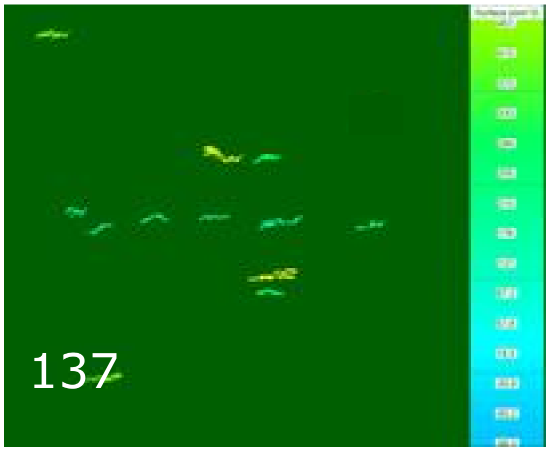
(½ and ¼ volumes:) Hand Dispensed Using a Syringe



Phase 2: Experimental Analysis

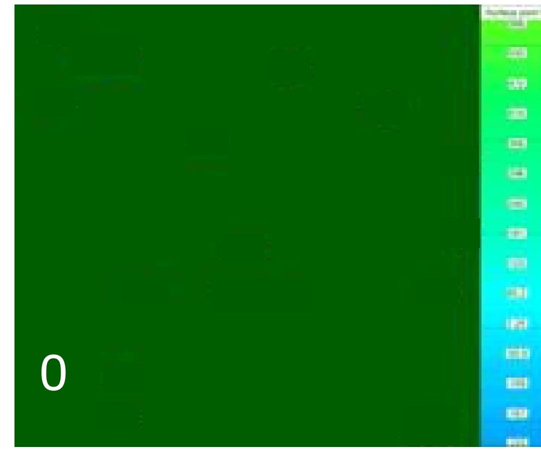
Drop Size Evaluation

Urethane



Robotic Dispense

½ Robotic Dispense



¼ Robotic Dispense

Making the drops smaller eliminated BLRT.

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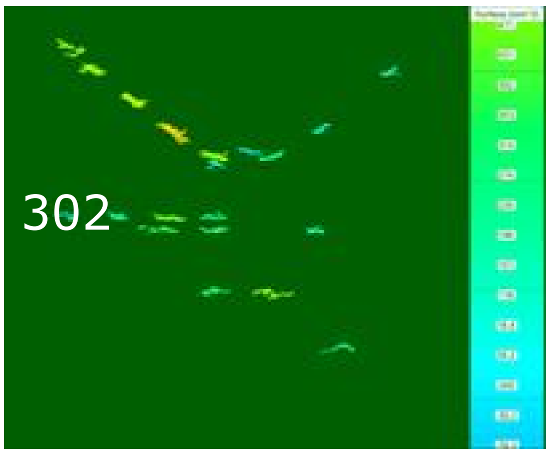
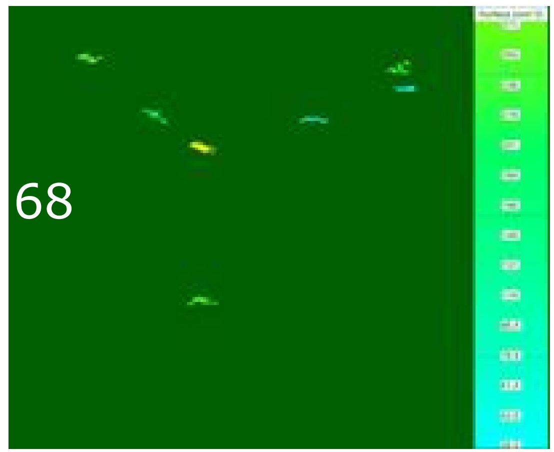
Phase 2: Experimental Analysis

Drop Size Evaluation

Epoxy



Robotic Dispense



½ Robotic Dispense

¼ Robotic Dispense

Making the drops smaller reduced BLRT.

Is this due to volume or squeeze-out?

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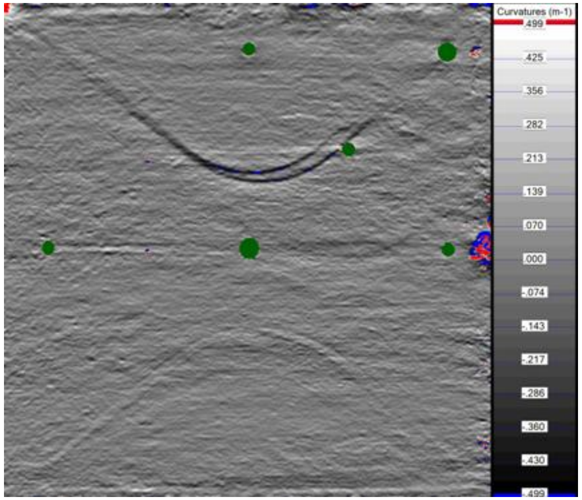
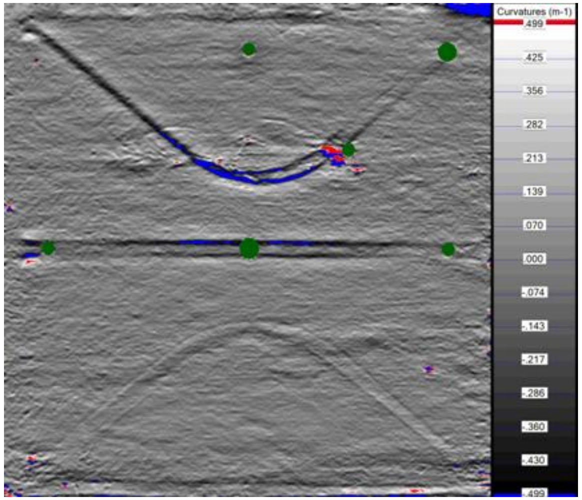
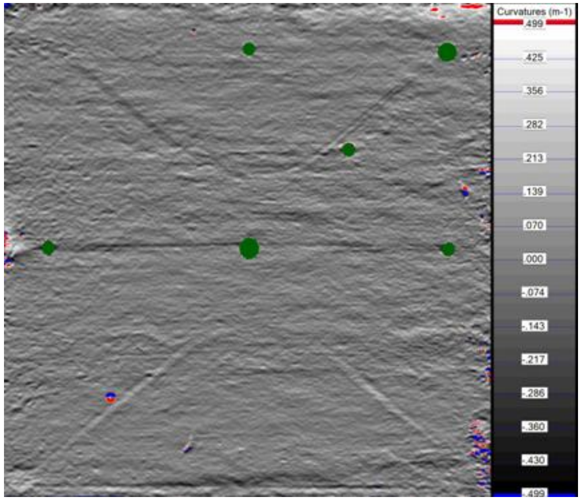
Squeeze-out vs. Adhesive Volume



"Standard Dispense"
1mm nominal bond gap



"2X Dispense"
1mm nominal bond gap



"2X Dispense"
3mm nominal bond gap

Squeeze-out appears to be more of a concern than the volume of adhesive.

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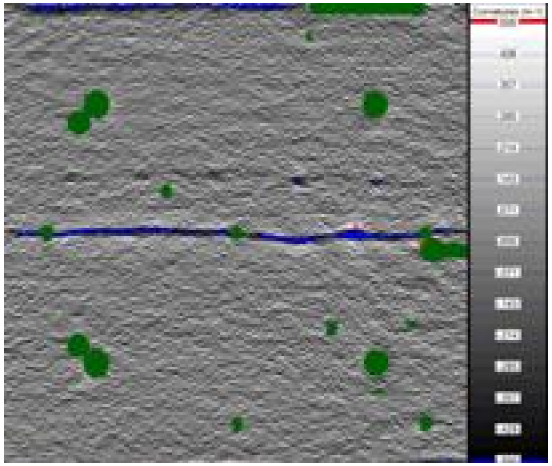
Phase 2: Experimental Analysis

Freestanding Outers – Epoxy

- Apply Adhesive to an Outer Panel
  - Bead Across the Center
  - Large Drops
  - Small Drops

  Hand Dispensed Using a Syringe (Large Drops, Small Drops)
- Cured in the fixture (300°F) until dry



Adhesive causes more distortion on a freestanding outer panel than on an assembly!

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Future Work

- Evaluate Variations on Measurement System Hardware to Improve Repeatability & Reproducibility
- Complete Additional Experiments
  - Mastic screening
  - Panel density and inner panel thickness
  - Generate experimental data to validate CAE model development
- Begin Development of Analytical Models
  - Develop a validated model for BLRT on a freestanding outer
  - Develop a validated model for BLRT on a “Basic” Assembly
  - Develop a validated model for BLRT caused by Stand-offs on the inner panel bond flange
  - Use the model to explore the effectiveness of different design strategies

ACC Bond-Line Read-Through Project

Summary

- Surface distortions caused by BLRT can now be quantitatively measured
- Experimental data generated in this project has identified several key material and process factors for which analytical models must account
- The ability to predict BLRT will allow OEMs to immediately reduce closure outer panel thickness (and therefore WEIGHT) by 25%.
- This technology will allow the use of minimum thickness panels when Class "A" carbon fiber SMC becomes technically and financially viable.